Effectiveness of Barnyard Best Management Practices in Wisconsin

Introduction

In 1978, the Wisconsin Legislature committed to protecting water quality by enacting the Nonpoint Source Water Pollution Abatement Program. Through this program, cost-share money is provided—within priority watersheds—to control sources of nonpoint pollution. Most of the cost-share dollars for rural watersheds have been used to implement barnyard Best Management Practices (BMPs) because barnyards are believed to be a major source of pollutants, most notably phosphorus. Reductions in phosphorus loads of as much as 95 percent have been predicted for the barnyard BMPs recommended for priority watersheds.

Previous studies of barnyard BMPs have often focused on individual BMPs, such as a filter strip below a concrete feedlot. Study results have been sufficient to predict the potential benefits of several individual barnyard BMPs, and the combined benefits of these BMPs have been estimated with the computer model BARNY (Wisconsin Department of Natural Resources, 1994). The output from the model has been used to develop management recommendations for phosphorus reduction in priority watersheds. The best way to evaluate the true benefits of a combination of barnyard BMPs is to monitor changes in the receiving water. However, very little information has been collected in Wisconsin to document such benefits.

The U.S. Geological Survey (USGS), in cooperation with the Wisconsin Department of Natural Resources, investigated the effectiveness of barnyard BMPs in two rural watersheds—Otter Creek and Halfway Prairie Creek. The purpose of this investigation was to determine how much pollutant reduction could be achieved by a system of barnyard BMPs. An upstream-downstream (above-and-below) experimental design was used to isolate the pollutant loads coming from a critical barnyard on each creek. Automated, intensive streamwater sampling was conducted during storm-runoff periods before and after the BMP systems were implemented. The concentrations of selected constituents in the streamwater samples and streamflow data were used to compute loads for the constituents contributed to the creeks by each barnyard during pre- and post-BMP storm-runoff periods. The data were analyzed to determine how effective each barnyard BMP system was in improving water quality.

View of upstream and downstream sampling stations at Halfway Prairie Creek (below) and close-up of upstream sampling station (right).

Description of Study Area

Otter Creek is within the Sheboygan River Priority Watershed (fig. 1). The drainage area is 9.2 square miles at the downstream sampling station, and land use is 67 percent agricultural (Bachhuber and Foye, 1993). Halfway Prairie Creek is within the Black Earth Creek Priority Watershed (fig. 1). The drainage area is 16.1 square miles at the downstream sampling station, and 60 percent of the land is used for agriculture (Eagan and Morton, 1989). Each stream (especially Halfway Prairie Creek) is typified by degraded aquatic habitat due to excessive sediment and nutrient loading from nonpoint sources—mainly cropland and dairy operations—and recreation is limited by low fish populations and by high concentrations of fecal coliform bacteria.

The investigated barnyards were identified by watershed managers as critical nonpoint-pollution sources based on output from BARNY. BARNY estimated total phosphorus loads produced by each barnyard in the watershed and then ranked each barnyard. Barnyards with the highest ranks (greatest total phosphorus loads) were considered to be critical sources within the watershed. Inputs for the BARNY model included lot size and surface type, additional contributing drainage area, and herd size. At the time of the modeling, the Otter Creek barnyard had a 0.2-acre concrete feedlot and an additional contributing

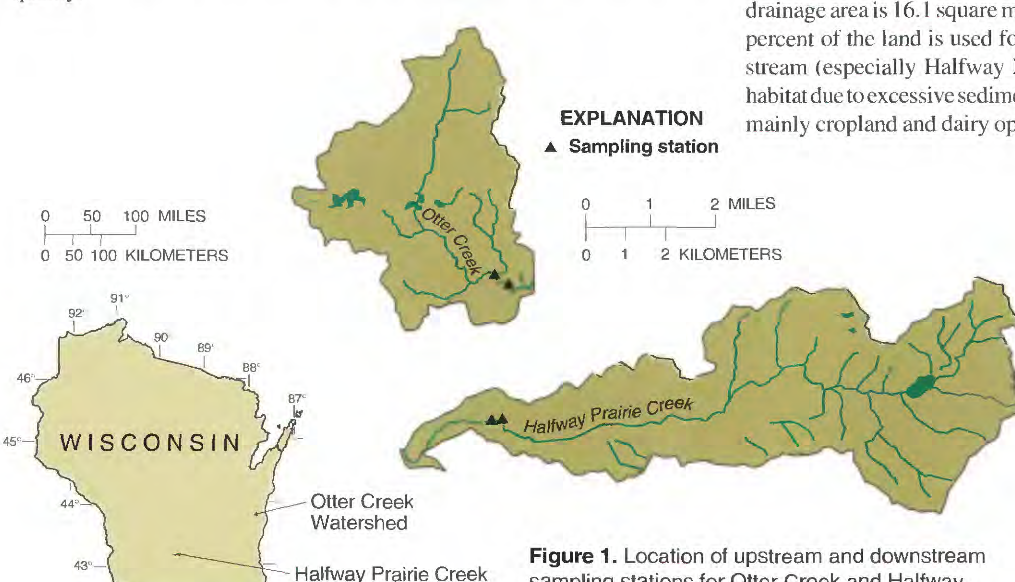


Figure 1. Location of upstream and downstream sampling stations for Otter Creek and Halfway Prairie Creek.

drainage area of 0.5 acres; the Halfway Prairie Creek barnyard measured 0.7 acres (concrete surface) and 1.1 acres, respectively. During the study, approximately 50 cows were kept in the Otter Creek barnyard, and approximately 100 cows were kept in the Halfway Prairie Creek barnyard.

Barnyard Best Management Practices

All of the recommended BMPs were implemented at both the Otter Creek and Halfway Prairie Creek barnyards, and the systems are similar. Surface runoff is diverted away from the livestock areas of each barnyard, and direct precipitation is conveyed by a sloped concrete surface and retaining wall to a screened collection box where most of the large solids are trapped. The effluent is gravity-piped to a concrete pad and graveled area, which evenly distributes the liquid onto a grass filter strip. The filter strip at Otter Creek borders the stream, whereas the filter strip at Halfway Prairie Creek is located on the opposite side of a highway, approximately 200 feet away from the stream. Cows that were previously allowed to roam the stream and banks at each site have been fenced in and can cross the stream only at a gravel-lined channel crossing. Sampling stations were established close to the barnyards to minimize non-barnyard inflows; however, a field near the barnyard at Otter Creek could have contributed to the instream loads between the upstream and downstream sampling stations, especially during periods of intense runoff. As part of the barnyard BMP system, a grassed swale was installed downgradient from this field to help minimize runoff.

Sampling Methods

Sampling stations were established on Otter Creek in April 1994 and on Halfway Prairie Creek in April 1995. At each stream, one station was upstream, and another station was downstream from the investigated barnyard. At the upstream sampling stations, streamwater levels and precipitation were continuously monitored, and discrete streamwater samples were collected automatically with a refrigerated water sampler. At the downstream stations, only streamwater samples were collected.

The drainage area of a single barnyard-runoff source is typically small compared to the drainage area upstream from that barnyard. Consequently, it may be difficult to detect measurable differences between the upstream and downstream streamwater-sample concentrations because the amount of pollutants contributed by a single barnyard-runoff source can be a small percentage of the amount of pollutants contributed from upstream areas (Spooner and others, 1985). The sampling design at Halfway Prairie Creek was modified to reduce the potential for this problem. First, the water samplers were activated by precipitation—rather than streamwater levels—and were programmed to collect time-integrated samples for an initial three-hour period. After this period, samples were collected in response to the rise and fall of streamwater levels, as in the pre-BMP setup at the Otter Creek stations. This modification was also made to the Otter Creek sampling design for the post-BMP monitoring period. The second modification at Halfway Prairie Creek was the direct electronic connection between the upstream and downstream stations, which allowed the collection of concurrent samples at the two stations.

Streamwater samples were collected during storm-runoff periods at both Otter Creek and Halfway Prairie Creek when the channels were free of ice. With the exception of one snowmelt period each for the pre- and post-BMP monitoring periods at Otter Creek, all of the runoff was produced by rainfall. Table 1 shows the number of pre- and post-BMP storm-runoff periods sampled, as well as the dates of collection. Samples were analyzed for concentrations of suspended solids, total phosphorus, ammonia, biochemical oxygen demand (BOD), and fecal coliform bacteria.

	Otter Creek		Halfway Prairie Creek	
	Pre-BMP	Post-BMP	Pre-BMP	Post-BMP
Number of storm-runoff periods sampled	12	15	11	11
Dates	4/94–10/95	4/96–6/97	4/95–7/95	4/96–6/97

Table 1. Number of pre- and post-BMP storm-runoff periods sampled and dates of collection for Otter and Halfway Prairie Creek

Continuous streamflow (calculated from the recorded streamwater levels) and instantaneous concentration data were used to estimate loads of suspended solids, total phosphorus, ammonia, and BOD for individual storm-runoff periods. Loads (in pounds) were computed by summing the product of streamwater-sample concentration and streamflow rate for each storm-runoff period (Porterfield, 1972). Microbial loads of fecal coliform bacteria were computed similarly; however, the units are in total colony-forming units (in the volume of water that flowed past the sampling station during a storm-runoff period).

Testing of Experimental Design

A critical aspect of obtaining useful conclusions for this study was the ability to document that downstream loads were significantly greater than upstream loads before the BMP systems were implemented. Results from statistical tests revealed that, for the pre-BMP period at both creeks, downstream loads of total phosphorus, ammonia, BOD, and microbial loads of fecal coliform bacteria were significantly greater than upstream loads. At Otter Creek, pre-BMP downstream loads of suspended solids also were significantly greater than those upstream. These significant differences indicated that each barnyard was an important contributor to the instream loads of total phosphorus, ammonia, BOD, and fecal coliform bacteria for the storm-runoff periods monitored; in addition, the barnyard at Otter Creek was also an important source of suspended solids.

Photos of investigated barnyard at Otter Creek both before (above) and after (right) implementation of Best Management Practices.

Differences Between Pre- and Post-BMP Barnyard Loads

The difference between upstream and downstream constituent loads was computed for each pre- and post-BMP storm-runoff period. These differences were considered to be the load contributed by each barnyard. In some instances, these differences were negative because inherent sampling and laboratory analysis errors were larger than the actual differences between the upstream and downstream loads. Barnyard contributions of total phosphorus for pre- and post-BMP runoff periods at Otter and Halfway Prairie Creeks are shown in figure 2.

Large differences in meteorological conditions—such as rainfall—between the pre- and post-BMP storm-runoff periods could potentially bias the results of data analyses. To test whether meteorological conditions differed, rainfall, rainfall intensity, runoff volume, and rainfall-runoff ratio for the pre- and post-BMP storm-runoff periods were statistically compared. No significant differences between pre- and post-BMP monitoring periods were detected for either Otter Creek or Halfway Prairie Creek. Any differences between pre- and post-BMP barnyard loads are therefore most likely due to the implementation of the barnyard BMP systems and not to differences in meteorological conditions.

A comparison of upstream and downstream loads after the BMPs were implemented indicates that both BMP systems improved water quality, at least for total phosphorus (fig. 2). In fact, at both creeks, post-BMP loads of total phosphorus, ammonia, and BOD contributed by the barnyard were statistically lower than pre-BMP loads. In addition, post-BMP loads of suspended solids and microbial loads of fecal coliform bacteria at Otter Creek were also statistically lower than in the pre-BMP period. The pre-BMP data analyses at Halfway Prairie Creek showed that the barnyard was not a significant contributor of suspended solids to the stream; therefore, a significant decrease in post-BMP suspended solids was neither anticipated nor detected. Halfway Prairie Creek was an important contributor to the stream loading of fecal coliform bacteria for the pre-BMP period; however, a significant decrease between pre- and post-BMP periods was not observed. It is probable that a source of fecal coliform bacteria was not controlled during implementation of the BMPs.

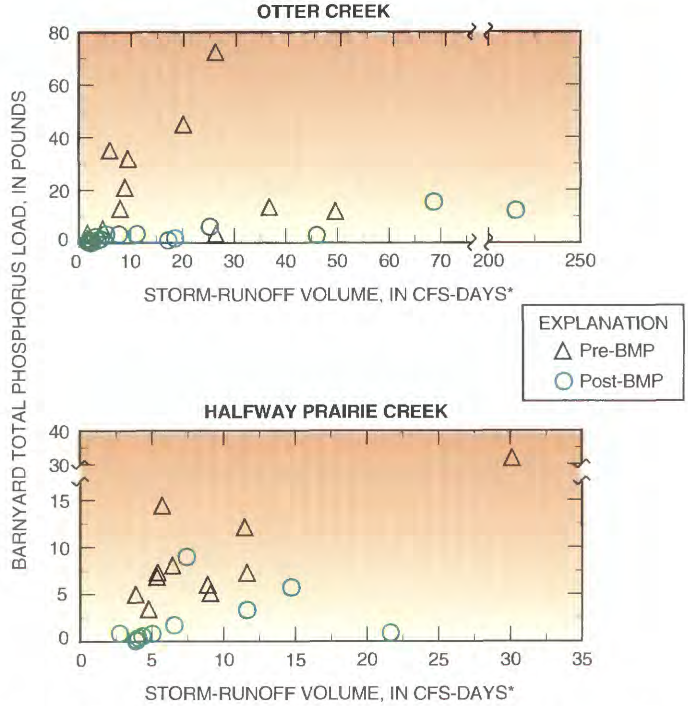


Figure 2. Total phosphorus load contributed by Otter Creek and Halfway Prairie Creek barnyards as a function of storm-runoff volume for the monitored pre- and post-BMP storm-runoff periods.

*CFS-day (cubic foot per second-day) is equivalent to 86,400 cubic feet or 646,317 gallons.

Pollutant Reductions Achieved By Barnyard Best Management Practices

The bar graphs in figure 3 (on back page) indicate that both barnyard BMP systems have reduced loads in the stream for each constituent. Each bar represents the median of all the differences between upstream and downstream constituent loads for both pre- and post-BMP storm-runoff periods. Although these medians could have been used to determine the percentage reduction achieved by each barnyard BMP system, it was decided that use of the Hodges-Lehmann estimator would be a more accurate approach (Helsel and Hirsch, 1992, p. 132).

The Hodges-Lehmann estimator is the median of all possible pairwise differences between pre- and post-BMP barnyard loads. This median difference was then divided by the pre-BMP median barnyard load for each constituent. The result was a percentage load reduction for each constituent.

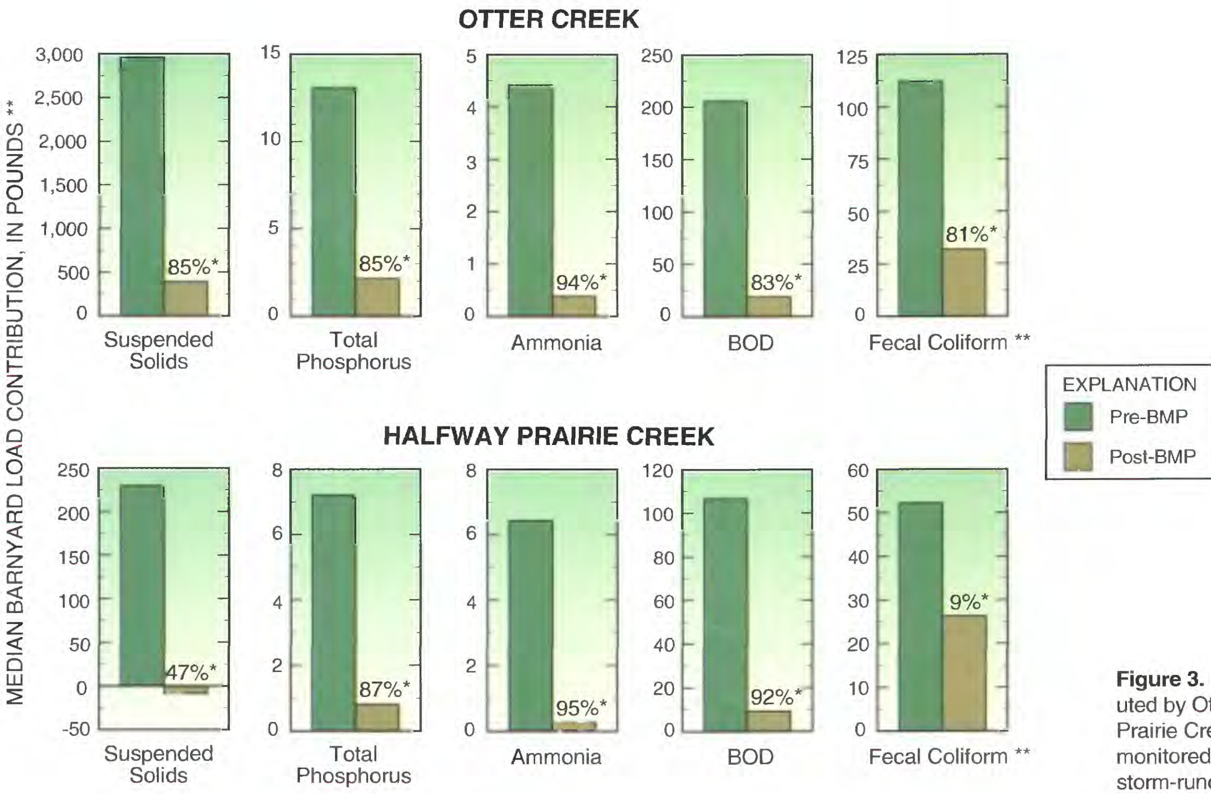
The Hodges-Lehmann estimator greatly improved the accuracy of percentage reductions for suspended solids and fecal coliform bacteria at Halfway Prairie Creek, where the difference between the two methods of calculation was more than 40 percent each. Use of the Hodges-Lehmann estimator did little to improve the accuracy of percentage reductions for the remainder of the constituents at Otter Creek and Halfway Prairie Creek, however, where the difference between the two methods was generally less than three percent.

The barnyard BMP system at Otter Creek has reduced loads of suspended solids by 85 percent, total phosphorus by 85 percent, ammonia by 94 percent, BOD by 83 percent, and microbial loads of fecal coliform bacteria by 81 percent; the respective loads at Halfway Prairie Creek have been reduced by 47, 87, 95, 92, and 9 percent.

Watershed planners for Otter Creek and Halfway Prairie Creek assumed that implementation of the designed barnyard BMP systems could lead to phosphorus load reductions of approximately 95 percent for each barnyard (Pat Sutter, Dane County Land Conservation Department, written commun., 1997). The reductions in phosphorus found in this study—nearly 90 percent for both barnyards investigated—indicate that this assumption is reasonable, at least for open-water periods.

The percentage reductions in loads for Otter Creek might have been lower if sampling had included all runoff periods occurring with frozen ground, when filter strips are not expected to work efficiently (Schellinger and Clausen, 1992). If the ground was assumed to be frozen between December 15 and March 15 of each year, one out of the three runoff periods occurring

Photos of investigated barnyard at Halfway Prairie Creek both before (above) and after (left) implementation of Best Management Practices.



* Percentage reduction is computed by dividing the Hodges-Lehmann estimator for pre- and post-BMP barnyard loads by the pre-BMP median barnyard load.

** Fecal Coliform microbial load in 10^{11} colonies.

Figure 3. Median loads contributed by Otter Creek and Halfway Prairie Creek barnyards for the monitored pre- and post-BMP storm-runoff periods, and percentage reduction in loads achieved by barnyard BMPs. *

with frozen ground was sampled during the pre-BMP period at Otter Creek. None of the 18 runoff periods occurring with frozen ground were sampled during the post-BMP period at Otter Creek. Because the filter strip at Halfway Prairie Creek is located on the opposite side of a highway and approximately 200 feet from the creek, the absence of data for runoff events during frozen ground conditions would likely have no affect on the measured efficiency of the BMP system.

Summary

At both Otter Creek and Halfway Prairie Creek, post-BMP loads of total phosphorus, ammonia, and BOD contributed by the investigated barnyards were significantly less than pre-BMP loads. Post-BMP loads of suspended solids and microbial loads of fecal coliform bacteria were significantly less than pre-BMP loads at Otter Creek, but not at Halfway Prairie Creek. The high reductions observed during open-water periods for phosphorus at each barnyard were similar to those described for barnyard systems in each priority watershed plan.

The upstream-downstream experimental design worked well, not only for measuring the magnitude of loads contributed by the investigated barnyards but also for documenting the load reductions resulting from BMP system implementation. This technique will most likely have merits in studies of other rural nonpoint BMPs, such as streambank erosion, rotational grazing and buffer strips, and their effectiveness in improving water quality.

By: Todd D. Stuntebeck, U.S. Geological Survey; and
Roger T. Bannerman, Wisconsin Department of Natural Resources

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For more information, please contact:

District Chief
U.S. Geological Survey
8505 Research Way
Middleton, WI 53562
(608) 828-9901
www: http://wwwdwimdn.er.usgs.gov

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Banner graphic: Karen Lonsdorf

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